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ENVIRONMENTAL AND TECHNOLOGICAL DETERMINANTS OF ORGANIZATION DESIGN: A CASE STUDY

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October 1968

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ABSTRACT

This paper reports a longitudinal case study of the Commercial Airplane Division of the Boeing Company. The first part analyzes the structure and coordination processes as a function of the technology. The section illustrates the concepts developed by James D. Thompson. After about 1964 the environment for Commercial aircraft changed considerably. Thus after describing the change, the changes in organization structure and process are related to the environmental change. The article is concluded with general comments on the organization design problem.

The relationship between an organization's technology and environment and its structure has become one of the major foci of empirical[1] and theoretical[2] work in organization theory. This paper, like the work of Lawrence and Lorsch, reports some empirical evidence which is relevant to the environment-technology-structure relationship. However, where Lawrence and Lorsch report on cross-sectional data, the evidence reported here is from a longitudinal viewpoint.

The Lawrence and Lorsch cross-sectional data were used to show that for a given environment, firms vary in their effectiveness by the degree to which they adopt coordinating mechanisms appropriate to their environments. Then holding effectiveness constant and at a high level, it was shown that these coordination devices appear with the decreasing stability of different environments. This study examines the changes in organization structure which took place in response to environmental changes. Implicit is the assumption that the organization studied was effective before the environmental changes and made the structural modifications in order to remain effective. Such an assumption seems quite reasonable.

The study was performed with the cooperation of the Commercial Airplane Division of The Boeing Company, Seattle, Washington. The data were collected by the author and two graduate students. The team spent a little over two months in residence while collecting the data. The methods of data collection consisted of extensive interviews with the management, reading Boeing internal documents, and observation of meetings. This paper represents the author's interpretation of the data subject to a review by Boeing management.

The Commercial Airplane Division organization is represented in Figure 1.

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[1] Paul R. Lawrence and Jay W. Lorsch, Organization and Environment (Boston, Mass.: Harvard University, 1967).

[2] James D. Thompson, Organizations in Action (New York: McGraw-Hill, 1967).

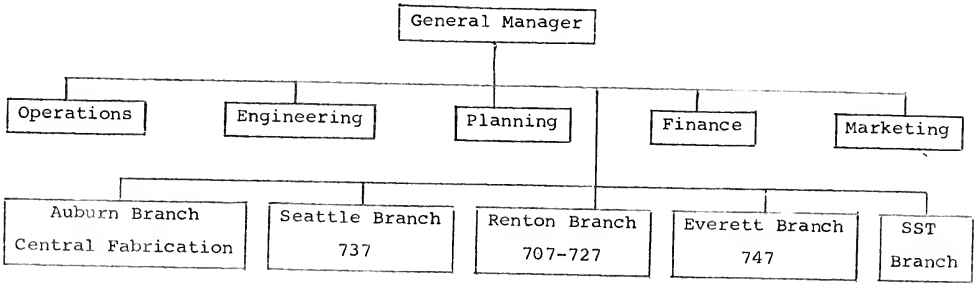

Figure 1 Commercial Airplane Division Organization Chart

Most of the positions represented are manned by personnel of a vice-presidential status. The first line shows the division functional staff. The second line represents the operating branches. The Auburn branch acts in a support capacity fabricating parts which cannot be economically produced by the product branches. The other branches are responsible for the design, fabrication, and assembly of an aircraft type. These product branches are the focus of the current study.

The remainder of the article is divided into three parts. The first describes the task performed at a product branch, the nature of the interdependence among sub-units, and the form of organization used to coordinate the work prior to the environmental change. This section is developed around the concepts and propositions of James D. Thompson. These concepts will be used throughout the paper. The second part describes the environmental change. Last, the organizational modifications which are attributed to the environmental change are described.

I. Structure and Coordination - Before Change

This section is to describe the structure and processes of a product branch organization. The first part is a brief description of the task and work flow. The next part reviews the concepts developed by Thompson[3] concerning interdependence, structure, and coordination. The last part operationalizes Thompson's concepts in terms of the task of a product branch.

A. Task and Work Flow

The product branches have the responsibility for designing and building the aircraft assigned to them. The process can be conceived as a work flow process whose purpose is to convert aerodynamic equations and wind-tunnel data into airplanes. Figure 2 diagrams the sequence of steps in the process.

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[3] Ibid., Chapter 5

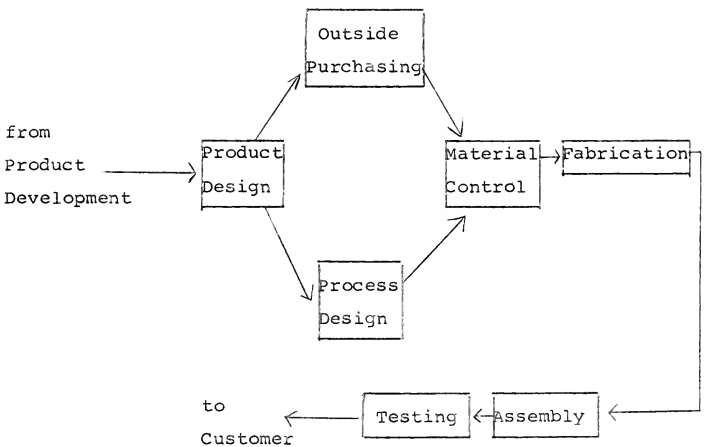

Figure 2 Work Flow at a Product Branch

The product branch receives the preliminary design from Product Development after the decision is made to introduce the model. The first step is to perform the detailed design of the aircraft down to each part and subassembly. The next step depends on whether the part is to be produced internally or externally. If it is produced externally, the purchasing department takes over upon completion of the design effort to begin acquisition of the part. Some items such as engines are designed as well as produced externally. If it is produced internally, the process design engineers must create the necessary manufacturing plans and tooling designs for the fabrication and subsequent assembly operations.

Following the design and acquisition steps, the material control function distributes the material and manufacturing plans for the sequential production operations. They monitor progress of parts and subassemblies and perform the necessary paperwork for reordering. Since each plane consists of about 100,000 parts, this is no simple task.

After the material has been acquired and the manufacturing methods are designed, the actual fabrication begins. The next step is another material control step where several fabricated parts are collected and issued to be joined as a subassembly. Next is a quality control inspection. This same sequence then repeats until subassemblies become major subsections which are joined in the final assembly area. Next the plane is rolled out onto the field where final installations are made and preflight inspection takes place. Then the aircraft is flight tested, certified by the FAA, accepted and flown away by the customer.

This process is repeated for each customer. Although each customer may purchase a 707 with the same external structure, the interiors and

electronics systems need to be redesigned. The different locations of food serving units necessitate the restressing of floors. In addition, each airline has pilots trained on different navigation equipment. Some foreign airlines have interior equipment in metric measurements. This means that there is substantial redesign of the product and therefore redesign of the process for each customer. When a new aircraft model is introduced, the sequence shown in Figure 2 is a major undertaking.

This process takes place in a time interval ranging from a little over a year to about two years. Time depends, among other things, on the amount of custom designing. For the introduction of a new aircraft, the sequence to design, produce, and test requires about three years. The process is performed at the product branches which are organizations of about 10,000 people. The cost to the customer ranges from several million for a 737 to around twenty million for a 747. A typical production rate would be about ten aircraft a month in the mature stages of development. This gives some perspective of the magnitude of the undertaking.

B. Interdependence, Coordination, and Structure

The type of organization structure and form of coordination have been hypothesized to depend upon the type of interdependence contained in the task[4]. Thompson has identified three types of interdependence. These are illustrated schematically in Figure 3.

The first and most simple type is pooled (a) interdependence. Departments having pooled interdependence affect each other only to the extent that they share the same pool of resources or affect a common

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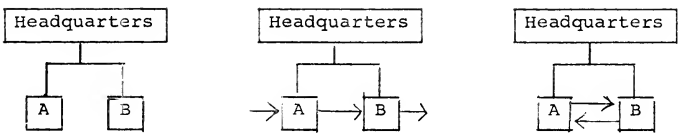
[4] ibid.



(a) Pooled (b) Sequential (c) Reciprocal

Figure 3 Types of Interdependencies

constraint in an additive manner. For example, all product design engineers designing parts and subassemblies are interdependent due to a constraint on total weight of the airplane. Weight must be below a specified amount in order to meet the customer specifications for speed, range, and operating economy. The interdependence is pooled because weight used by one designer is not available for use by another designer. But neither designer affects the other except through the constraint. An important point is that each affects the constraint in an additive manner.

Two departments have sequential interdependence (b) when the output of one department is the input to the other. A good example is the fabricating shop feeding an assembly shop. The parts must be cut and machined before they are assembled into more complex components. These sequences are technologically determined. The departments that have sequential interdependence also have pooled interdependence.

The third type is reciprocal interdependence (c). Two units whose operations directly affect the other are reciprocally interdependent. A process and a product designer are reciprocally interdependent. Clearly, a process to produce a part cannot be designed until the part is designed. The process depends very much on the shape and material of the part. However, if the product is to be produced economically, the product should be modified to facilitate cheaper methods of production. Inputs from both designers are needed to affect the final design. It should be noted that reciprocal interdependence also implies sequential and pooled interdependence as well.

Thompson's second set of concepts concerns the types of coordination and their matching with the types of interdependence. The first type of coordination can be achieved by standardization.

> This involves the establishment of routines or rules which constrain action of each unit or position into paths consistent with those taken by others in the interdependent relationship. An important assumption in coordination by standardization is that the set of rules be internally consistent, and this requires that the situations to which they apply be relatively stable, repetitive and few enough to permit matching of situations with appropriate rules.[5]

A second type is coordination by plan. The planning process involves the establishment of schedules and targets to govern the actions of the interdependent units. Planning is appropriate to more dynamic situations than is standardization. Plans quite often consist in changing the parameters in established decision rules.

The third type of coordination is mutual adjustment. This "... involves the transmission of new information during the process of action." The task is sufficiently unpredictable that pre-established decision rules and plans cannot be prepared. Thus as the predictability of the task changes the appropriate form of coordination changes from standardization to planning to mutual adjustment. Also the burden on the decision and information systems increases as the form changes from standardization to mutual adjustment. In terms of organizational resources expended, mutual adjustment is the most costly and standardization is the least costly.

One of Thompson's main propositions is that there is a distinct parallel between the types of coordination and the types of interdependence. This means that standardization is used in the most simple form - that of pooled interdependence. Schedules and plans are appropriate for sequential interdependence, while mutual adjustment is the appropriate form for reciprocal interdependence.

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[5] Ibid., p. 56.

The organization design problem can now be defined. It is this problem that will serve as the basis for discussion in the subsequent sections. The problem can be stated by two hypotheses. The first is that organizations structure themselves so as to minimize coordination costs. It follows that the first priority is given to reciprocally interdependent activities which require mutual adjustment coordination mechanisms. These positions are grouped together first so to facilitate the ongoing communication processes. Next, attention is given to sequentially interdependent units. These are grouped together. Last, units with pooled interdependence are grouped together if any units remain.

The second hypothesis is that organizations group together activities of like kinds of work in order to achieve the benefits of process specialization.[6] By grouping together all work requiring machinists, the organization can produce all work requiring machining with the fewest number of machinists. Process specialization increases the utilization of the means of production. Also by grouping together like activities the volume of work performed in a given place is increased. According to Adam Smith, "the division of labor is limited by the extent of the market."[7] Thus process specialization allows a finer division of labor and therefore the use of specialized means of production and greater technical expertise.

These two propositions define the organization design problem because usually these two bases for departmentalizing an organization structure will conflict. The design problem is one of balancing the

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[6] James G. March and Herbert A. Simon, Organization (New York: Wiley, 1958) p. 25.

[7] Adam Smith, The Wealth of Nations (New York: Modern Library, 1937).

benefits of process specialization against the costs of coordination. Process specialization is important for effective performance on subtasks while coordination is important for integrating all the subtasks for effective completion of the whole task. Lawrence and Lorsch have recently stated this problem in a little different form as simultaneously seeking integration (effective coordination) and differentiation (process specialization).[7]

The problem of balancing coordination costs and specialization benefits will be the basis of subsequent sections. Although there is no explicit measurement of these costs and benefits, they can be inferred from the organization design decisions. Also it can be inferred that the costs and benefits have changed and likewise the design has changed. Let us proceed to the form of organization before the change.

C. Structure and Coordination at a Product Branch

This section is to describe the organization structure at a product branch and provide some rationale for it in terms of the design propositions. As such, the description serves as an illustration of the propositions rather than an empirical test.

The first proposition stated that organizations group together activities so as to minimize coordination costs. Therefore, let us first examine those activities which have reciprocal interdependence and require the more costly forms of coordination. Table one lists some of the more important types of reciprocally interdependent diads and the source of their interdependence.

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[7]Lawrence and Lorsch, op. cit., Chapter 2.

Table One

Reciprocally Interdependent Diads

	Actors	Source
1.	Product Designer - Product Designer	Integrity of design and compatibility of parts
2.	Product Design- Process Design	Producibility of parts designs
3.	Product Design- Purchasing	Availability of new devices & technology
4.	Product Design- Factory	Discovery of design flaws & quality rejects
5.	Process Design- Factory	Discovery of process design flaws and improvements

Table one lists five sources of reciprocal interdependence. Clearly, this is too large a grouping for mutual adjustment to coordinate the activities. It is at this point that Thompson introduces the notion of a hierarchy.

> On occasion, reciprocal interdependence is so extensive that to link all of the involved positions into one group would overtax communication mechanisms. When this occurs, organizations rank-order the interdependent positions in terms of the amount of contingency each poses for the others. Those with the greatest intercontingency form a group, and the resulting groups are then clustered into an overarching second-order group.[8]

If the interdependent pairs in table one were rank-ordered by criticalness, the first pair, product designer-product designer, would be most critical. Meeting the customer design specifications and the FAA safety standards are clearly the top priority goals. Thus the product designers are grouped toether. Even here there are too many people to form one group. Thus there is a wing department which is subdivided into various sections. The smallest group consists of those engineers that design parts that must fit together to form an assembly. The holes for rivets and fasteners must line up with fairly close tolerances. Likewise the wing must fit onto the body. However, once the points of attachment have been determined, the wing and body designers can function independently of one another. However, as design problems arise the attachment points may need to be changed necessitating some mutual adjustment. But the amount contingency between body and wing is not as great as between successive wing sections. Figure four shows the engineering department which is grouped to exhaust the

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[8]Thompson, op. cit., p. 59.

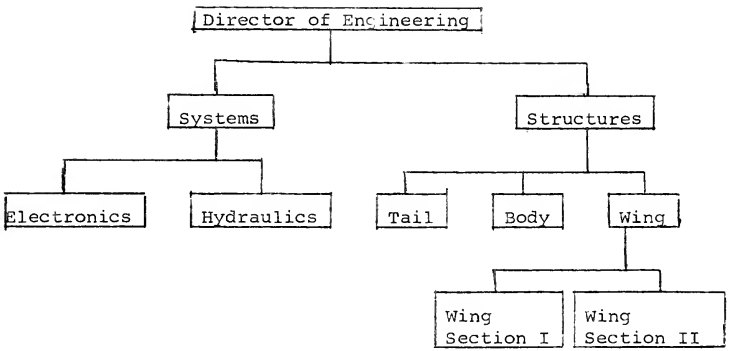

Figure 4 Design Engineering Organization

reciprocal interdependence of type I in Table one. Each level of hierarchy contains reciprocal interdependence but the contingency between units on a level decreases at each higher level.

Although all engineers are grouped into one unit, some process specialization is sacrificed to achieve integrity of design to meet all necessary specifications. A technical staff is maintained to provide the specialized expertise in stress analysis and aerodynamics. The addition of the staff specialists is a compromise solution to the design problem wherein the coordination costs are kept to a minimum in the "line" groupings and expertise is obtained through staff specialists. In addition the organization which minimizes coordination costs also allows process specialization. Figure four shows that all structural engineers are in one group and electrical and hydraulic systems engineers are in another.

Among the remaining sources of reciprocal interdependence, there is no clear priority. However, different methods of handling these independencies can be identified. The first method applies to the interdependence between product design and process design. Recall from the previous section that product designs are an input to the process design and process design considerations are an input to the product design. In order to achieve a product that meets customer specifications and can be produced at a reasonable cost some mutual adjustment must take place. It seems logical that this interdependence would be handled by a continued elaboration of the hierarchy to form an all encompassing engineering group as indicated in Figure 5. This is not the case however. It will be shown later that process design is part of the manufacturing organization. The way in which the interdependence is actually handled is interesting because it illustrates that there are a number of strategies for handling interdependence.

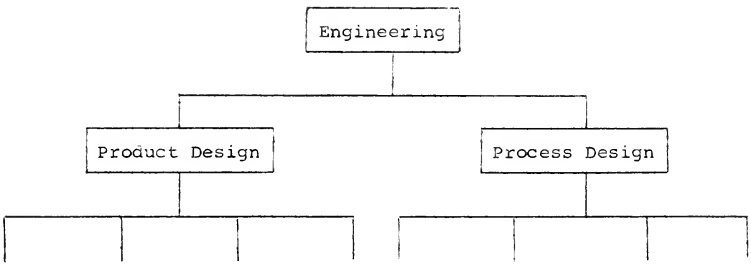

Figure 5 Engineering Structure to Handle Reciprocal Interdependence between Product and Process Design

The strategy for handling the product design-process design interdependence has been to eliminate it before a project is assigned to a product branch. In Figure 2 the work flow indicates that product development is the first step. It is in this division group that the reciprocal interdependence between product design, process design, and marketing is worked out. It is identical to processes described by Lawrence and Lorsch in the plastic firms.[9] Thus most of the major issues requiring design adjustments have been made prior to the detailed design. Mutual adjustment is facilitated by fewer people and fewer time constraints.

Some additional provision for mutual adjustment must be made however. The planned design always runs into unforseen problems requiring changes. To handle mutual adjustment between product and process designers, some process specialization is sacrificed. If process design did not have to coordinate with other functions, it would be organized around process specialties such as numerical control, plastic molding, sheet metal work, parts machining, etc. Instead, as shown in Figure 6, the process design organization reflects the product design organization. This facilitates direct contact between designers and first line managers. These are the people who are conversant with the problems and can make the necessary adjustments. The process specialties are represented as staff advisors. This represents a compromise between the costs of coordination and benefits of process specialization. This structure also facilitates the handling of sequential interdependence.

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[9] Lawrence and Lorsch, op. cit.

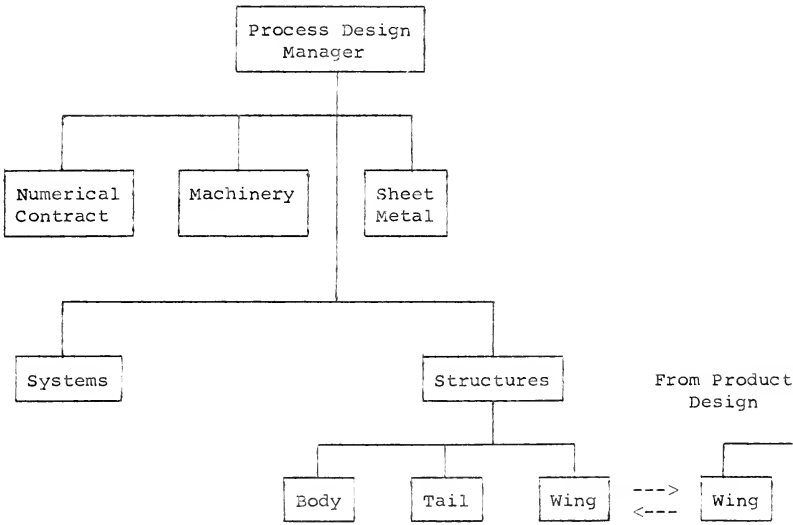

Figure 6 Process Design Organization

The structure just described permits mutual adjustment when a limited amount is needed. This was the case for the 707 and the 727 airplanes. The 707 had a prototype designed, built, and tested before undertaking the final design and production. The 727 had four years of development and wind tunnel testing before final design. A good deal of the reciprocal interdependence was worked out in this manner. In addition, the product design group was experienced from previous airplane designs and learned how to modify designs for economic manufacture. For these reasons, interaction was not often needed even though interdependence was present.

The reciprocal interdependence between product design and purchasing was handled in a little different manner. Some mutual adjustment took place in product development where purchasing is also represented. Additional mutual adjustment is necessary as problems arise and as new technology becomes available in the market. Like process design, purchasing does not form a second order grouping with product design. Unlike process design, however, purchasing's organization is not a mirror image of product design. Instead, the purchasing organization is divided into units which deal with homogeneous groupings of vendors.[10] This is more important for the performance of the purchasing function. The mutual adjustment takes place in two ways. There is some direct contact between product designers and purchasing, but the strucutre does not encourage establishment of close relationships. The other method is with a group that maintains contact with the market and the engineers and suggest changes.

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[10]Thompson, op. cit., p. 70.

The last type of reciprocal interdependence exists between the two design groups and the factory. In the process of converting a paper airplane to a metal airplane some of the design assumptions prove faculty. The foreman discovers parts that do not fit in the tools or fail to fit each other. This may be due to faulty workmanship, faulty product design, faulty process design, or some combination. When these problems arise, there is need for mutual adjustment to redesign process or product. Both design groups handle this interdependence in the same way. They establish liaison departments in their organizations and station the liaison engineers in the factory. Figure 7 illustrates the structure of this group. They are organized to assist factory departments rather than be engineering specialty. If difficult design problems arise, they are taken back to the design groups.

These liaison departments are good examples of integrators.[11] Also the number of integrators varies directly with the certainty of the task.[12] Figure 8 shows how the number builds after the start of the design of a new aircraft. It peaks when all the parts arrive and assembly begins. The number drops off to a sustaining force after about the first ten aircraft are complete. Mutual adjustment takes place again through a structural arrangement.

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[11] Lawrence and Lorsch, op. cit.

[12] This is consistent with recent additional findings by Lawrence and Lorsch where the percentage of special integrating personnel varied with the certainty of the task and the type of interdependence. In their study the plastic firms had 22%, the food processers 17%, and the container firms 0%. See Jay W. Lorsch and Paul R. Lawrence, Environmental Factors and Organization Integration, paper prepared for the Annual Meeting of the American Sociological Association, August 27, 1968, Boston, Mass.

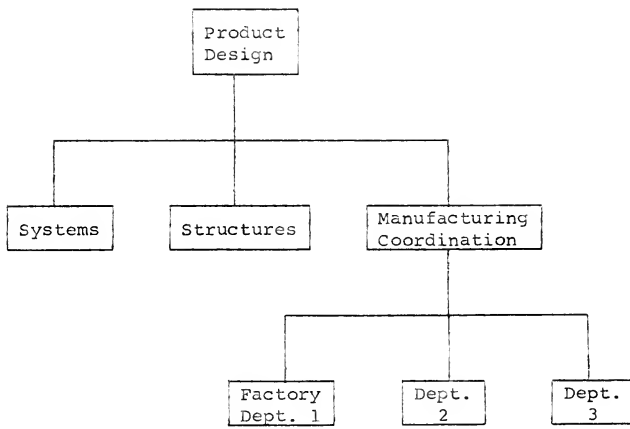

Figure 7 Product Design Organization

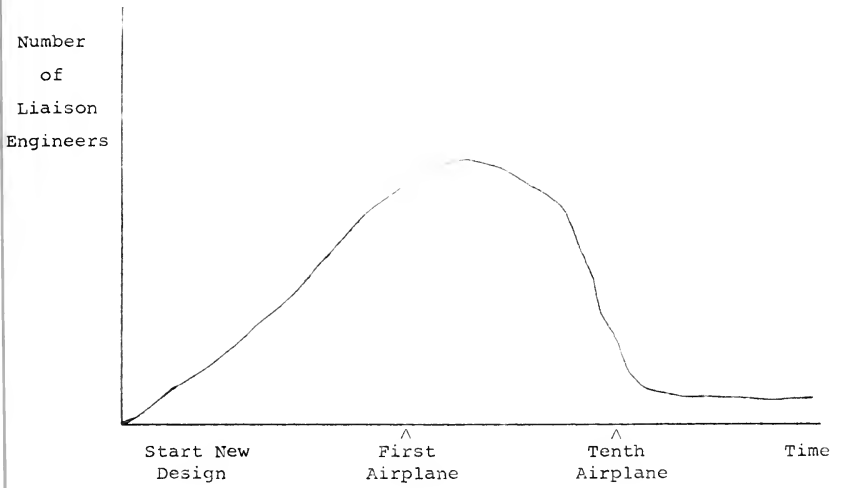

Figure 8 Variation of Integrating Personnel with Task Certainty

This exhausts the major sources of reciprocal interdependence. Each of the sources have structural arrangements to facilitate the mutual adjustment of the interdependent groups. Still following Thompson's propositions, the next step is to look at sequential interdependence, the next most costly to coordinate.

> After grouping units to minimize coordination by mutual adjustment, organizations under norms of rationality seek to place sequentially interdependent groups tangent to one another, in a cluster which is localized and conditionally autonomous.[12]

It is at this point that an interesting design choice arises. Since planning is the form of coordination used for sequential interdependence and planning costsincrease with growth in the number of variables and length of lines of communication, it is expected that organizations will place the planning job in the smallest cluster of serially interdependent units. If this was the case a product branch organization would appear like Figure 9. The wing organization has the serial interdependence depicted in Figure 2 and there is little interaction with other components (body, tail, etc.) until final assembly. Thus these components could do their own scheduling with the product design departments.

The price of such an organization is the loss of process specialization benefits. This is particularly true in purchasing and fabrication. In purchasing there will be common vendors in each group and therefore duplicate contacts. In fabrication there is expensive equipment which must be fully utilized and duplication is costly. As a result, the organization is structured as shown in Figure 10.

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[12]Thompson, op. cit., p. 58.

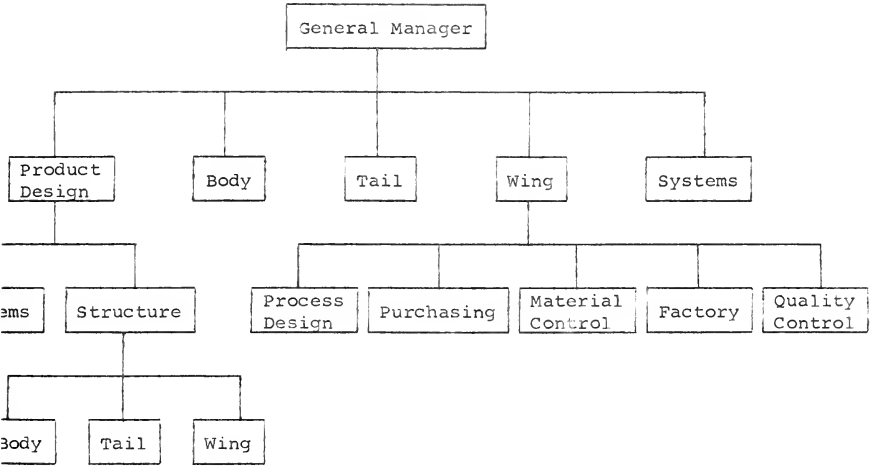

Figure 9 Product Branch with Sequentially Interdependent Clusters

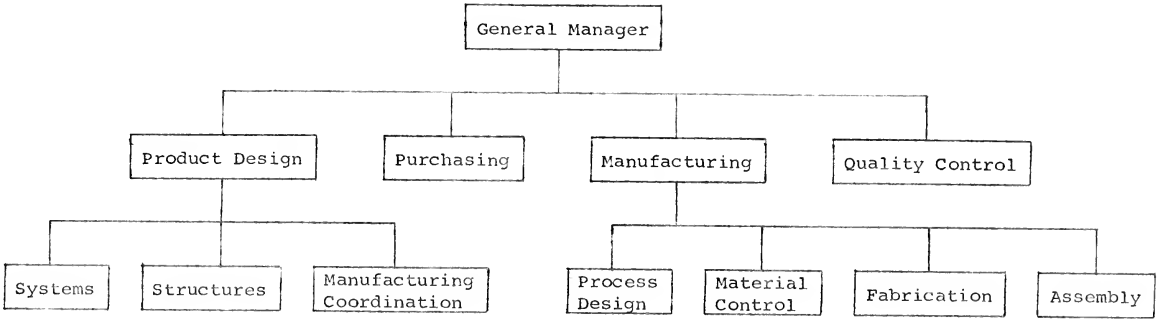

Figure 10 Functional Organization of Product Branch - Before Change

Manufacturing represents a first order grouping of sequentially interdependent units. The product branch under the general manager becomes a second order grouping of sequentially interdependent units.

The organization of Figure 10 gains complete utilization of production facilities but at the cost of increasing the difficulty of coordinating the work flow. With planning and scheduling as the means of coordination for sequential interdependence, the coordination costs increase as the number of variables and the amount of communication increase. Some process specialization is sacrificed within function to reduce these coordination costs. It was mentioned earlier that process design was organized to facilitate interaction with product design to resolve both reciprocal and sequential interdependence. Also purchasing was departmentalized so as facilitate interaction with homogeneous vendor groupings. If in addition the material control, fabrication, assembly, and quality control were each departmentalized so as to best perform their subtasks, the number of separate departments through which an order must pass gets very large. The scheduling and sequencing problems would be very large. Thus the material control and quality control functions are departmentalized on the same basis as the fabricating and assembly departments. This gives some continuity to the work flow, reduces the number of variables in the scheduling problem, and facilitates direct managerial contact for adjacent functional supervisors.

The scheduling job is still quite substantial. After product design, orders must pass through purchasing, process design, fabrication, and assembly, all of which are organized on different bases. Process design and assembly are quite similar however. The communication costs

would be substantial if frequent reporting of all orders in all departments were required. However, the communication costs have been reduced by adding slack time between start and finish of the design, produce, and test sequence. The effect is to add delays in the flow between functions. This takes the form of order backlogs for paper processing functions and in-process inventories for parts processing functions. This uncoupling of sequential functions greatly reduces the frequency of reporting and the need for rescheduling. Problems arising in one function are less likely to affect the operations of other functions. When they do, the organization hierarchy, direct contact of affected supervisors, and rescheduling can handle it. Thus the inventory and backlog buffers reduce the amount of information processing and decision-making needed for effective integration.

The scheduling task itself is performed by departments within product design and manufacturing. The group within manufacturing schedules the work flow from process design to quality control. The group within product design handles the sequential interdependence between the design groups. In addition, these two groups along with one in purchasing are partially responsible for the sequential interdependence between the functions in the product branch.

There is one additional department which enters into the scheduling process. (See Figure II) This is the program manager's office. This group collects information for the general manager and aids in the integration of the functions. In addition the program manager maintains information needed by marketing and represents the branch to the customer. The program manager chairs a committee consisting of the functional scheduling groups and marketing. This committee decides on internal

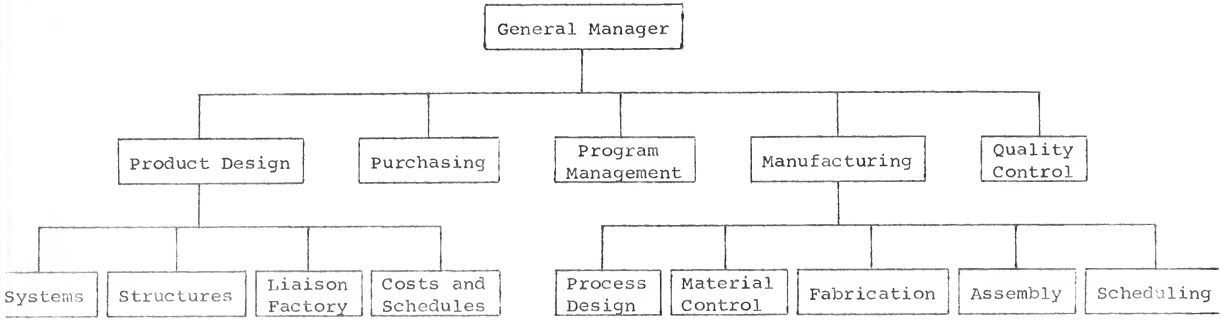

Figure 11 Typical Product Branch Before the Change

start and finish dates for each customer order. These dates become the schedule that handles the second order sequential interdependence. Then each group breaks out more detailed schedules for start and finish dates within each function.

This method of coordination works very well as long as every department meets its due date. The addition of slack time mentioned before allows for this. It is only when due dates are missed that additional coordination effort is needed. There are two possible types of schedule disruption which require additional coordination effort--predictable and unpredictable causes.

The predictable disrputions result from the constant flow of design changes from product design engineers. The design changes are caused by attempts to update technology, by rejects from quality control, by liaison engineers, and by customer requests. Since design changes are originated in the product design step, the change can have effects on all subsequent functional activity. The additional coordination effort takes the form of a committee called a change board. Each function and sales have a permanent representative on the board. They meet daily to discuss schedule and budget changes. The changes are then communicated to the affected groups.

The unpredictable schedule disruptions usually arise due to uncertainties in task performance. The uncertainty varies between functions. The design groups have the greatest uncertainty. The uncertainty varies with the maturity of the project and the state of the art of the design. Thus the introduction of new models introduces the greatest uncertainty. What makes the problem difficult is that the schedule disruptions are most likely to occur in the design functions which are at the start of the sequential work flow. Therefore they can potentially disrupt all

subsequent activity. Some of the disruptions can be handled by direct managerial contact, by re-scheduling, and through the hierarchy. But when numerous problems arise, the decision-making capacity of the organization is exceeded. One measure of the goodness of the sequential coordination is the number of stockouts. A stockout occurs if a part or assembly is not available for installation as scheduled. Stockouts significantly increase labor costs. Figure 12 illustrates the stockout history of the Commercial Airplane Division.

Figure 12 illustrates quite graphically the effect of uncertainty on organizational performance. Periods of high stockouts coincide perfectly with the introduction of new models. Thus the sequential coordination strategy and structure just described are best suited for stable tasks. The high levels of stockouts were tolerated as transients and the organization returned to normal performance after the completion of the first few aircraft. This was judged as less costly than adding additional coordination effort or changing structure as suggested in Figure 9 to self contain some of the sequential interdependence. This kind of performance was the price paid for process specialization in the purchasing and manufacturing functions.

Thus the primary problem of a product branch is the scheduling of sequentially interdependent activities when the initial activities are highly unprogrammed. This scheduling is accomplished by scheduling departments, scheduling committees, and the use of order backlogs and in-process inventories. Some process specialization is sacrificed in non-critical activities to reduce the size of the scheduling problem. Also the backlogs and inventories reduce the communication costs.

There is also a good deal of coordination by standardization. Routines exist for monitoring the flow of the 100,000 parts through

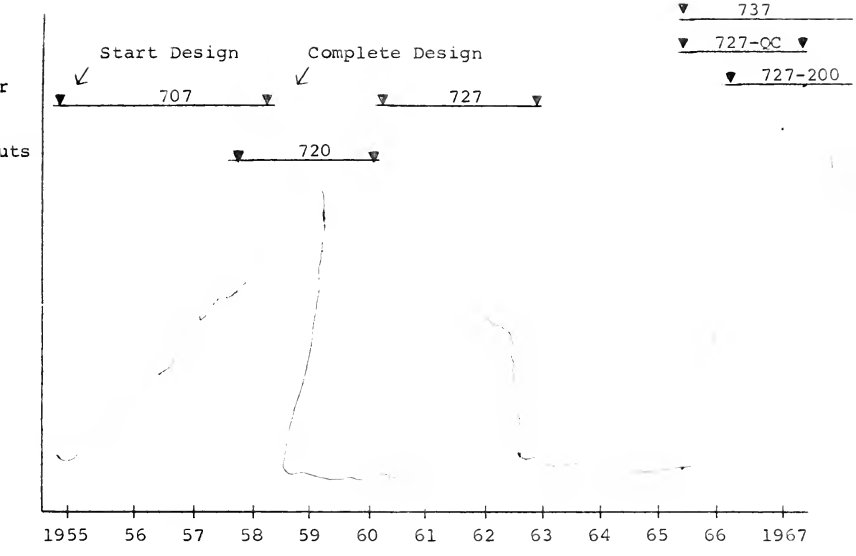

Figure 12 Stockout History of Commercial Airplane Division

the sequence of functions. Another routine is called configuration management. This is to guarantee that the aircraft actually assembled is identical to the specifications given by the customer. Otherwise the wrong equipment could be placed in it as the aircraft goes through all the functions over a two-year period.

A product branch emerges from this discussion as a complex organization. It makes use of all the coordination devices referred to by Lawrence and Lorsch. It uses integrating liaison departments, scheduling departments, scheduling committees, direct managerial contact, superior-subordinate contact, and an extensive paper work system. This system worked very well before 1964. After 1964 some changes were necessary to maintain effective operations.

II. Environmental Changes

During the period 1963, 1964, and 1965 some significant changes took place. First, the Commercial Airplane Division completed its transition from military to commercial business. The contract for the KC-135 production was completed and they were unsuccessful in proposals for TFX (F-111) and the C-5A.

A second change was the enormous increase in commercial air traffic and therefore demand for commercial aircraft. This caused a rapid build-up of men, material, and facilities. Such a build-up always taxes a firm's financial resources. The loss of government business is important in the respect that the government always paid progress payments to finance build-ups of this nature. Until recently the commercial airlines did not.

The third and most significant change took place in the market. The problem facing Boeing with the 707 was to demonstrate the efficiency of jet aircraft over propeller aircraft in the commercial market. Boeing's success brought direct competition from Douglas's DC-8 and

Convair's 880. When Boeing introduced the 727 the problem was to establish a market for jet aircraft in the medium range routes. Douglas's response this time was not direct competition but a new short range aircraft, the DC-9. In the market expansion the short range routes are very attractive.

Now the problem facing Boeing is not to establish a market but to meet the opportunities as quickly as possible. The introduction of the short range 737, the new versions of the 727, the giant jet 747, and the SST, all take place under competitive pressures from the DC-9, an elongated DC-9, a commercial derivative of Lockhead's C-5A, the stretched version of the DC-8, and the British-French Concorde.

There are two important implications of this third change. First, adding longer lead time is no longer tolerable as a method of absorbing uncertainty and reducing scheduling costs. The financial constraints are against accumulating in-process inventories and the market constraints favor reducing lead time rather than increasing it. The second implication is that the 737 and 747 received less time in product development than the 707 and 727. This leaves more problem-solving and hence greater uncertainty for the design-production sequence. Let us now examine the responses to this new situation.

III. Responses to Environmental Change

The growth in the number of aircraft models and volume of sales called for the change from a functional organization to the product branch structure as indicated in Figure I. This change was effected in the summer of 1966. The specifics of the interbranch and division relationships are still being worked out. The concern of this section, however, is with the interfunctional changes which have taken place at the product branches in designing and manufacturing the aircraft.

The environmental changes had a direct impact on the strategy for coordinating functions. The need to reach the market quickly caused less research and development effort prior to committing to performance targets with the airlines and it meant that increased lead time was not an acceptable method of uncoupling the sequential functions. This means that the uncertainty of the task was increased and simultaneously the system was made more vulnerable to uncertainty caused schedule disruptions. The branches were faced with design choices which consisted of strategies that allowed acceptance of increased numbers of stockouts, that increased coordination effort, or that consisted of changes in structure which reduced the need for coordination. The response was primarily increased coordination effort. Major structure changes were avoided because the periods of high uncertainty were temporary.

The changes to be described were made in the 1966-67 period. From Figure 12 it can be seen that this was a period of unusually high stockout activity. It was also during this period that stockouts slowed production and subsequently caused a financial crisis at Boeing's principle competitor the Douglas Company. This fact helped eliminate possible strategies to accept higher levels of stockouts.

The first coordination mechanism was added between product design and process design. It is here that the uncertainties are the greatest and there is both reciprocal and sequential interdependence. The additional coordination was performed by a liaison group of process designers who were physically stationed in the product design area. Their first responsibility was to work with the product designer and suggest design alternatives which allow less costly manufacturing processes. Due to the environmental changes, the reciprocal interdependence requires communication and interaction to achieve the necessary coordination. This is due to several factors. First, the reciprocal interdependence was

not completely worked out in product development. Second, the amount of communication exceeded the capacity of direct managerial contact. And finally the increased volume of activity brought in new engineers who were not familiar with past practices. These combined to create a need for liaison engineers.

The liaison group also aided in the coordination of sequential interdependence. If the product designers were late in completing a design, this delayed the start of the process design activity. In order to put a part back on schedule, the process design group would have to resort to overtime. However, the liaison men take advantage of the fact that a part design does not have to be 100% complete before the process design can begin. The tool design can be started if rough dimensions and material are known. Thus the liaison engineers keep the process designers supplied with work by bringing them partially completed parts designs. In this way the design efforts are run in parallel rather than in series with the liaison man as the communication link.

Thus the liaison group facilitates mutual adjustment and allows the removal of slack time from the schedule without causing disruptions. The liaison group also represents an increase in coordination costs since it is used in addition to, not instead of, the schedule and direct managerial contact. However, once the design of the new aircraft is complete, the liaison men resume normal duties as process designers or liaison men elsewhere. The activity is needed only in periods of high uncertainty.

The liaison group used in the manner described was not an innovation. It had been used in a similar manner in the World War II construction of the B-17 and B-29. It had not been used recently. Its use was initiated this time by the manufacturing manager.

The second type of coordination device to be used was the task force. The task force groups provided additional interfunctional coordination as the new designs flowed through purchasing, material control, fabrication, assembly, and testing. The primary purpose of the groups was to supplement the formal hierarchy and provide a quick reaction capability to avoid damaging schedule disruptions as problems arise. One of the task forces was organized by major section - wing, body, tail, etc. Another was organized by airplane number. That is a couple of men were assigned to each of the first six planes to be produced. All members of the task forces worked full time for the task force as long as it existed.

The task forces were able to collect information on an informal basis by walking through the plant and telephoning managers. This interfunctional information gave them the basis for setting priorities. This interfunctional information was not available anywhere else. The information collected and displayed by the program manager was interfunctional but was not detailed enough nor current enough to provide for the setting of priorities as problems arose. Since the groups within the task forces were responsible for relatively independent tasks, they were able to collect this information and respond to problems as they arose. Also by spending a good deal of time in the plant, they were able to work with people who were most knowledgeable about the problem.

The task forces represented a temporary structure change which modified the authority relationship during periods of high uncertainty. During the period of new design introduction, the task force set priorities on what to do next. Since they had information which cut across functions and were not identified with any single function, the task force members were in a better position to determine priorities than were the functional

managers. The functional managers still made decisions relating to who would do the work and how to do it. During periods of task certainty, the functional managers did not need priorities other than "follow the schedule!". But during a new model introduction, the assumptions on which the schedule is based often prove wrong as problems arise. As the problems arise, the information collecting activities of the task force place them in the position to set new priorities. As the task becomes more predictable, the schedule becomes a more reliable priority device and the task force is not needed. They generally disband after about six to ten planes have been built. The task force organized around the airplane sections is a good example of the matrix organization.

The task force again represents additional coordination effort and cost. Like the liaison man, it is used in addition to, not instead of, the normal means of coordination. It is necessary to replace the slack time that has been removed from the schedule with additional means of coordination.

The two task forces were initiated by different people. The same manufacturing manager that introduced the liaison group introduced the task force on the 727-200 program which was being merged into the same organization currently producing the 727 and the 707. He felt the task force was necessary to see that the new program received the needed attention. The other task force was the result of an audit team report to the Division General Manager. The behind schedule condition prompted the action on the part of the General Manager.

The liaison group and the task force are limited in the degree of integration they can achieve. The liaison group is organized to link only two functions. The task force links multiple functions but is limited in the amount of information it can collect because it collects

information by informal means. These are expensive means since it implies that high priced managers go about seeking information. To conserve this cost they usually wait until a problem arises and collect information relevant to the problem. If no problems arise, the schedule is followed. Since the task force is organized into self-contained units, such as a wing group, this further limits the amount of information they need, without ignoring important variables. Since they crossed functions, they were in a better position than functional managers to set priorities. Although direct contact between functional managers could be used, the task force had a greater capacity for priority setting. In a similar manner when the design tasks are linked to the parts acquisition and assembly stages, the problems exceed the information processing and decision-making capacity of the task force.

The problem facing the task force is to make patchwork modifications to the aircraft design so as to maintain the delivery schedule and meet FAA quality standards. However, the task force takes the basic design and delivery schedule as given. This eliminates the reciprocal interdependence with marketing. The result is that the problem can be solved within the task force groups. The "givens" greatly reduce the number of alternatives facing the task force and reduces their need to collect information to evaluate alternatives. Thus the informal information system worked very well for the task force which began its operations after the design was completed. As previously mentioned the task forces followed the flow only through the manufacturing operations.

The use of liaison and task forces were not sufficient to cover the needs for additional coordination on the 747 program. There was needed addition interfunctional coordination since the design was not given. The problem was to integrate the design task as well as the

manufacturing task. Thus when a problem arose there were many alternative solutions. This created a need for information to estimate and evaluate the consequences of alternatives. With less research and development the design parameters were not as complete as prior programs. With the reduced lead time these design decisions had to be made without seriously disrupting the schedule. Of course activities could be rescheduled to facilitate the design task. These decisions place considerable pressure on the decision making apparatus.

An example of a hypothetical design problem can illustrate the magnitude of the decision problem. Suppose that the design group in systems was going to attempt a state of the art advance in the design of the actuator for the wing flaps.[13] It will operate hydraulically rather than electrically. This will increase its life, decrease its weight, and will take three months to develop. After two and a half months it appears that it will require another two months to complete the design. This requires a decision. One class of alternatives would involve continuing with the state of the art advance and seek ways to put the actuator back on schedule. One way would be to use the remaining slack time and have manufacturing work overtime. Another alternative would be to install the device at a later date. Also process design could design a faster and usually more expensive process to absorb the time. Or instead of subcontracting the fabrication work, it could be produced internally to save time. The customer may be willing to accept a month's delay. There is a time and a cost to each of these alternatives.

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[13] The wing flaps are the movable portions of the wing which expand the size of the wing on take-off and landing. The larger wing area creates more lift for take-off and more drag for landing. A smaller wing is preferable for cruising.

A second class of alternatives involves eliminating the state of the art advance and adopting a known actuator which could be operationalized in two weeks. However, the known actuator does not provide a weight saving and weight must be reduced some other way. Weight could be taken out of the airplane in other sections. It could be taken out by using lighter but more expensive materials such as titanium for stainless steel. Or the engine producer might be able to increase the thrust of the engine. This means the weight could be tolerated without reducing performance targets on speed, range, and operating economy. Thus, there are multiple alternatives which require evaluation. It is such a decision problem that the 747 product branch must frequently handle. The alternative creation and consequence evaluation require inputs from all functions, from vendors, and from customers. Likewise the final decision will require revision of task assignments, schedules, and budgets of all functions.

The organization design problem facing the General Manager on the 747 consisted of a choice between two alternatives. First, the decision making could be decentralized. That is, by finding some relatively independent groupings the magnitude of the decision problem could be reduced. By bringing the decision making down to the level at which the information exists, communication costs are reduced. This is consistent with Lawrence and Lorsch's findings that greater task uncertainty was correlated with greater influence at lower levels.[14]

However, this was not the choice of the General Manager. In addition to reducing the need for coordination, it is also possible to increase one's capacity to coordinate. Rather than decentralize the decision to the level at which the information exists, it is possible to bring the information up to the decision-making. This was the choice made

[14] Lawrence and Lorsch, op. cit., pp. 71-73.

on the 747 program.

The 747 strategy was implemented by making an organizational modification and by increasing the influence of the program manager's office. The organization of the product branch is shown in Figure 13. Other branches have recently followed by making similar changes in structure. The structure represents a more inclusive first order grouping of the sequentially interdependent functions which take place after product design. The second order grouping consists of coupling the reciprocally interdependent design units with the sequentially interdependent operations functions. Also there is coupling with the division marketing group and major subcontractors. The incomplete preliminary design requires substantial external interactions.

The other change was the increased influence of the program manager's office. It was this unit that aided in the information collection process. They increased both the detail and the currency of the information displayed in the management control center. Previously the information was used more for ex post evaluation rather than ex ante decision making. Detailed interfunctional information for decision-making had to be acquired informally by the task forces. Now there is a more formal information system to provide this data. The cost of the change is the large increase in clerical personnel to process the information.

More information does not necessarily result in better decisions unless there is an increase in the capacity to utilize it. For this purpose a PERT-like model of the design task was used.[15] These models

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[15] For the original article describing PERT and its use on the Polaris program see Donald Malcolm, John Roseboom, Charles E. Clark, and Willard Fazar, Application of a Technique for Research and Development Program Evaluation, Operations Research, 7 (October, 1959).

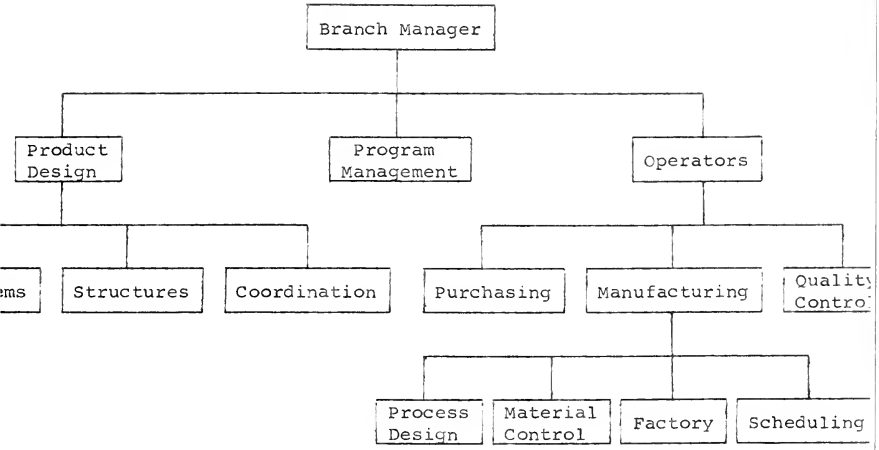

Figure 13 Product Branch Organization Responsible for 747

display graphically the technological sequence of tasks to be performed. It allows the cause and effect relationships to be traced quite easily. Thus if there is a design problem, all subsequent tasks affected can be identified and those managers called to a meeting to decide what to do with it. The use of PERT is credited with reducing lead time on the Navy's Polaris Program.

Thus the increase in task uncertainty and tighter coupling of functions was countered with more information and an increased decision-making capability. It seems easier to change from this design to one required for stable operations than it would be to change from a decentralized form to the normal centralized structure. Under the present system as the uncertainty is decreased, the amount of information will be decreased. The frequency of reporting can be reduced from daily to weekly, weekly to bi-weekly. The PERT system will not be needed. The number of information processing people can be decreased to a normal level as the task certainty increases. Although the form of coordination is different, its intensity still varies directly with the uncertainty of the task.

The task force described earlier operated under the principle of management by exception. This conserved the amount of information that had to be collected. The 747 information system by contrast operates on the principle of management by anticipated exception. As the status of the program is updated periodically, potential problems are anticipated and resolved before they become real problems. Many are resolved by interfunctional teams or committees. Once a specific problem has been identified, the functional personnel most familiar with the problem are assigned to a team to resolve it. The team exists until the problem is solved. All these teams are chaired by personnel of the program

manager's office and make use of information in the control room. These teams differ from the task forces in that the members are not full time team members. They are full time functional personnel that periodically meet until the problem is solved. There are several teams in action at any one time.

The use of committees to help coordinate sequential interdependence confirms another of Thompson's propositions. He proposes that sequential interdependence not handled by scheduling will be handled by committees. It is also interesting to contrast the committees and teams on the 747 with the change board committees. They represent two different committee strategies. The 747 program used the information system and PERT-like model to identify occassions for committee action, to create alternatives, and to assess and evaluate consequences.

The change board's activities were designed to eliminate the need for information. Instead of an information system it had elaborate classification schemes. Classification reduces the need for information by permitting much of the decision making to be done prior to the need for it.[16] Thus the problem facing the Change Board is to distinguish the type of event and change some parameters in the predecided solution. The Board is staffed by permanent representatives from each function who are trained in the appropriate classifications and responses. The price for this approach is that problem and solution do not match precisely. However, the problems are repetitive enough and small enough so that the costs of the mismatch outweigh costs of information collection and interaction to work out a solution for each problem individually. In addition, should a consequential problem arise, then additional effort

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[16] March and Simon, op. cit., p.163.

can be brought to bear. Thus, problems are solved by applying a classification scheme and then a programmed decision for events of that class. Events which are difficult to classify or are consequential trigger an exception mechanism which conserves problem solving effort.

The decision strategy of the 747 has taken the former approach because their problems are not repetitive and are consequential.

The change in the 747 program is the result of design decisions made by the 747 general manager and the program manager. The general manager did not come from the ranks of the Commercial Airplane Division. He came from outside the company. Most of the personnel in the program manager's office came from the aerospace group at Boeing to help staff the building-up operations. These people coming from the outside brought the ideas implimented on the 747 program.

This third section has described the increases in coordination effort--liaison men, task forces, interfunctional committees, and formal information systems--which were required to integrate the functional units under the new environmental constraints. Prior to the change, product branches removed the need for coordination by adding slack time to absorb the uncertainties inherent in the design process. The increased task uncertainty and reduced lead time brought forth the additional coordination efforts in the product branches so as to minimize schedule disruptions and stockouts.

Conclusions

This paper has tried to illustrate several points. First, the interdependence among organizational activities is determined primarily by the task or technology. The fact that a product branch was responsible for an airplane and that the airplane was to be designed as well as manufactured determined the major interdependencies among the activities.

2 A second point was that the magnitude of the coordination effort varied with the degree of uncertainty about the nature of the basic task. This was clearly illustrated by the response to the environmental change. It is also quite consistent with the work of others.[17]

3 The third point is that there is a multitude of coordination mechanisms which can successfully integrate the interdependent activities. This study described the use of peer relationships, liaison men, task forces, interfunctional committees, scheduling departments, formal information systems, decision models and superior-subordinate relations. The organization structure is to facilitate the use of these mechanisms.

4 A fourth point is that the appropriate combination of coordination mechanisms is a joint function of the interdependence and the task uncertainty. It is on this aspect of the organization design problem that Thompson's propositions are most useful.

5 The last point is that there is a richness of strategies available to the organization in designing its structure. This can be seen by recalling that uncertainty determines coordination effort. Recall also that the task uncertainty at a product branch was a function of the amount of prior research and development. Now both the amount of coordination effort and the amount of research and development are controllable variables for the organization. Therefore a strategy is called for to balance these two opposing costs. The richness develops when buffers and structure are controllable variables. In our illustration the use of slack time created inventory and backlog buffers. These buffers can reduce the amount of coordination effort for a given degree of uncertainty. Buffers also have costs of customer delay and inventory investment. This means that there are three interacting variables.

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[17] Lawrence and Lorsch, op. cit., Charles Perrow, A. Framework for the Comparative Analysis of Organizations, American Sociological Review, 32 (April, 1967), and Thompson, op. cit.

When the basis of departmentalization is also considered, there are four factors to be determined in the strategy. By reducing the amount of process specialization the amount of coordination effort can be reduced. Thus coordination effort varies directly with the degree of process specialization while holding constant the use of buffers and task uncertainty. The choice of the appropriate combination of buffers, process specialization,[3] uncertainty, and[4] coordination effort[5] for a given technology make up the organization design problem.[2] These factors considerably complicate the experimental design problem for comparative analyses.

JAN 6 '69

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